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KS 1855-3 (2008) (English): Thermal solar systems and components — Custom built systems — Part 3: Performance characterization of stores for solar heating Systems (Draft Standard)

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Thermal solar systems and components — Custom built systems — Part 3: Performance characterization of stores for solar heating Systems

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Thermal solar systems and components — Custom built systems — Part 3: Performance characterization of stores for solar heating Systems

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Foreword

This Kenya standard was developed by the Renewable Energy Resources Technical Committee under the supervision of the Electrical Industry Standards Committee and is in accordance with the procedures of the Bureau.

The test methods for stores of solar heating systems as described in this Kenya Standard are required for the determination of the thermal performance of small custom built systems as specified in KS 1855-1.

These test methods deliver parameters, which are needed for the simulation of the thermal behaviour of a store being part of a small custom built system.

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Thermal solar systems and components — Custom built systems — Part 3: Performance characterization of stores for solar heating systems

1 Scope

This Kenya Standard specifies test methods for the performance characterization of stores which are intended for use in small custom built systems as specified in KS 1855-1.

Stores tested according to this Kenya Standard are commonly used in solar hot water systems. However, also the thermal performance of all other thermal stores with water as storage medium (e.g. for heat pump systems) can be assessed according to this Kenya Standard.

The Standard applies to stores with a nominal volume between 50 and 3000 litres and without integrated oil or gas burner.

2 Normative references

The following referenced documents are indispensable for the application of this Kenya Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

KS 1852-2, *Thermal solar systems and components — Factory made systems — Test methods*

KS 1855-2, *Thermal solar systems and components — Custom built systems — Test methods*

ISO 9774, *Thermal insulation for building applications — Guidelines for selecting properties*

ISO 16528, *Boilers and pressure vessels*

ISO 9488, *Solar energy — Vocabulary*

ISO 9459-5, *Solar heating — Domestic water heating systems — Part 5: System performance characterization by means of whole — System tests and computer simulation*

3 Terms and definitions

For the purposes of this Kenya Standard the following terms and definitions together with ISO 9488 apply.

3.1
ambient temperature
mean value of the temperature of the air surrounding the store

3.2
charge
process of transferring energy into the store by means of an heat source

3.3
charge connection
pipe connection used for charging the storage device

3.4
combistore
store used for both domestic hot water preparation and space heating

3.5
constant inlet temperature ($\tilde{\vartheta}_{x,i}$)

temperature which is achieved during charge (x = C) or discharge (x = D), if the mean value $\tilde{\vartheta}_{x,i}$ over the period of 0.5 reduced charge / discharge volumes (see 3.34) is within $\tilde{\vartheta}_{x,i}$ ± 1) °C

3.6
constant flow rate ($\tilde{v}$)

flow rate which is achieved, when the mean value $\tilde{v}$ over the period of 0.5 reduced charge / discharge volumes (see 3.34) is within $\tilde{v}$ ± 10 %

3.7
constant charge power ($\tilde{P}_c$)

charge power which is achieved, when the mean value $\tilde{P}_c$ over the period of 0.5 reduced charge volumes is within $\tilde{P}_c$ + 10 %

3.8
conditioning

process of creating a uniform temperature inside the store by discharging the store with $\vartheta_{D,i}$ = 20 °C until a steady state is reached

NOTE The conditioning at the beginning of a test sequence is intended to provide a well defined initial system state, i.e., a uniform temperature in the entire store.

3.9
discharge connection

pipe connection used for discharging the storage device

3.10
dead volume / dead capacity

the volume / capacity of the store which is only heated due to heat conduction (e. g. below a heat exchanger)

3.11
direct charge / discharge

transfer or removal of thermal energy in or out of the store, by directly exchanging the fluid in the store

3.12
discharge

process of decreasing thermal energy inside the store caused by the hot water load

3.13
double port

a corresponding pair of inlet and outlet connections for direct charge / discharge of the store

NOTE Often, the store is charged or discharged via closed or open loops that are connected to the store through double ports.

3.14
effective volume / effective capacity

the volume / capacity which is involved in the heat storing process if the store is operated in a usual way

3.15
electrical (auxiliary) heating

electrical heating element immersed into the store

3.16
external auxiliary heating
considered as part of the store under test 3.17 auxiliary heating device located outside the store. The heat is transferred to the store by direct or indirect charging via a charge loop. The external auxiliary heating is not

3.17
heat loss capacity rate $(UA)_{s,a}$
the overall heat loss of the entire storage device per K temperature difference between the store temperature and the ambient air temperature

NOTE The heat loss capacity rate depends on the flow conditions inside the store. Hence a stand-by heat loss capacity rate and a operating heat loss capacity rate are defined. If $(UA)_{s,a}$ is to mentioned without specification, $(UA)_{s,a}$ represents the stand-by heat loss capacity rate.

3.18
heat transfer capacity rate
the thermal power transferred per K temperature difference

3.19
immersed heat exchanger
heat exchanger which is completely surrounded with the fluid in the store tank

3.20
indirect charge / discharge
transfer or removal of thermal energy into or out of the store, via a heat exchanger

3.21
load
the heat output of the store during discharge. The load is defined as the product of the mass, specific thermal capacity and temperature increase of the water as it passes the solar hot water system

3.22
mantle heat exchanger
heat exchanger mounted to the store in a way, that it forms a layer between the fluid in the store tank and ambient

3.23
measured store heat capacity
the measured difference in energy of the store between two steady states on different temperature levels, divided by the temperature difference between this two steady states

3.24
measured energy $(Q_{x,m})$
time integral of the measured power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.25
measured power $(P_{x,m})$
power calculated from measured volume flow rate as well as measured inlet and outlet temperature

3.26
mixed
state when the local store temperature is not a function of the vertical store height

3.27
model parameter

parameter used for quantification of a physical effect, if this physical effect is implemented in a mathematical model in a way which is not analogous to its appearance in reality, or if several physical effects are lumped in the model (e.g. a stratification number)

3.28
nominal flow rate ($\dot{v}_n$)
the nominal volume of the entire store divided by 1 h

3.29
nominal heating power (P_n)
the nominal volume of the entire store multiplied by 10 W/l

3.30
nominal volume (V_n)
fluid volume of the store as specified by the manufacturer

3.31
operating heat loss capacity rate $(UA)_{op,sa}$
heat loss capacity rate of the store during charge or discharge

3.32
predicted energy ($Q_{x,p}$)
time integral of the predicted power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.33
predicted power ($Q_{x,p}$)
power calculated from measured volume flow rate, as well as measured inlet temperature and calculated outlet temperature. The outlet temperature is predicted by numerical simulation

3.34
reduced charge / discharge volume
integral of a charge / discharge flow rate divided by the store volume

3.35
stand-by
state of operation in which no energy is deliberately transferred to or removed from the store

3.36
heat loss capacity rate $(UA)_{sb,s,a}$
heat loss capacity rate of the store during stand-by

3.37
steady state
state of operation at which at charge or discharge during 0.5 reduced charge / discharge volume (see 3.34) the standard deviation of the temperature difference, between store inlet and store outlet temperature of the charging / discharging circuit is lower than 0.05 K

NOTE In cases of an isothermal charged store rather constant temperature differences between the inlet and outlet temperature of the discharge circuit may occur during the discharge of the first store volume before the outlet temperature drops rapidly. This state is not considered as steady state.

3.38
store temperature
temperature of the store medium

3.39
Stratified

state when thermal stratification is inside the store

3.40
stratified charging
increase of thermal stratification in the store during charging

3.41
stratifier
device that enables stratified charging of the store. Common used stratifiers are e.g. convection chimneys or pipes with radial holes

3.42
theoretical store heat capacity
the sum over all thermal capacities $m_i \times C_{p,i}$ of the entire store (fluid, tank material, heat exchangers) having part of the heat store process

3.43
thermal stratification
state when the local store temperature is a function of the vertical store height, with the temperature decreasing from top to bottom.

3.44
transfer time ($t_{x,f}$)
time period during which energy is transferred through the connections for charge(x=C) or discharge (x=D). The transfer time is calculated over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

4 Symbols and abbreviations

C_s	thermal capacity of the entire store, in J/K
C_P	specific heat capacity, in J/(kg K)
P_n	nominal heating power, in W
$P_{x,m}$	measured power transferred through the charge (x=C) or discharge (x=D) circuit, in W
$P_{x,p}$	predicted power transferred through the charge (x=C) or discharge (x=D) circuit, in W
$Q_{x,m}$	measured energy transferred through the charge (x=C) or discharge (x=D) circuit, in J
$Q_{x,p}$	predicted energy transferred through the charge (x=C) or discharge (x=D)circuit, in J
t_{st}	time required to achieve a steady state, in s
$t_{x,f}$	transfer time for charging (x=C) or discharging (x=D) , in s
ϑ_a	ambient temperature, in °C
ϑ_s	store temperature, in °C
$\tilde{\vartheta}_{x,i}$	inlet temperature of the charge (x=C) or discharge (x=D) circuit, in °C
$\vartheta_{x,i}$	constant inlet temperature of the charge (x=C) or discharge (x=D) circuit, in °C

$\vartheta_{x,o}$	outlet temperature of the charge (x=C) or discharge (x=D) circuit, in °C
$(UA)_{hx,s}$	heat transfer capacity rate between heat exchanger and store, in W/K
$(UA)_{s,a}$	heat loss capacity rate of the store, in W/K
$(UA)_{op,s,a}$	operating heat loss capacity rate of the store, in W/K
$(UA)_{sb,s,a}$	stand-by heat loss capacity rate of the store, in W/K
V_n	nominal volume of the store, in l
$\dot{V}_n$	nominal flow rate, in l/h
$\tilde{\dot{v}}_x$	constant flow rate of the charge (x=C) or discharge (x=D) circuit, in l/h
$\Delta\vartheta_m$	mean logarithmic temperature difference, in K
$\varepsilon_{x,P}$	relative error in mean power transferred during charge (x=C) or discharge (x=D), in %
$\varepsilon_{x,Q}$	relative error in energy transferred during charge (x=C) or discharge (x=D), in %
ρ	density, in kg/m^3

5 Store classification

Hot water stores are classified by distinction between different charge and discharge modes. Five groups are defined as shown in Table 1.

Table 1 — Classification of the stores

Group	charge mode	discharge mode
1	direct	direct
2	indirect	direct
3	direct	indirect
4	indirect	indirect
5	stores that cannot be assigned to groups 1 to 4	

NOTE 1 All stores may have one or more additional electrical heating elements.

NOTE 2 Stores that can be charged or discharged directly and indirectly (e. g. a store of a space heating system with an internal heat exchanger for the preparation of domestic hot water) can belong to more than one group. In this case the appropriate test procedures or the assignment to one of the groups respectively, shall be chosen depending on its mode of operation.

6 Laboratory store testing

6.1 Requirements on the testing stand

6.1.1 General

The hot water store shall be tested separately from the whole solar system on a store testing stand.

The testing stand configuration shall be determined by the classification of hot water stores as described in Clause 5.

An example of a representative hydraulic testing stand configuration is shown in Figure 1 and Figure 2.

The circuits are intended to simulate the charge and discharge loop of the solar system and to provide fluid flow with a constant or well controlled temperature. The full test stand consists of one charge and one discharge circuit.

NOTE 1 If the store consists of more than one charge or discharge devices (e.g. two heat exchangers), then these are tested separately.

The testing stand shall be located in an air-conditioned room where the room temperature of 20 °C should not vary more than ± 1 K during the test.

Both circuits shall fulfil the following requirements:

— The flow rate shall be adjustable between 0.05 m^3/h and 3 m^3/h, by deviation < 2 %.

— The working temperature range shall be between 10 °C and 90 °C.

— The minimum heating power of the charge circuit shall be 15 kW.

— The minimum cooling power in the discharge circuit shall be 5 kW at a fluid temperature of 20 °C.

NOTE 2 If mains water at a constant pressure and a constant temperature below 20 °C is available, it is recommended to design the discharge circuit in a way, that it can be operated as closed loop or as open loop using mains water to discharge the store.

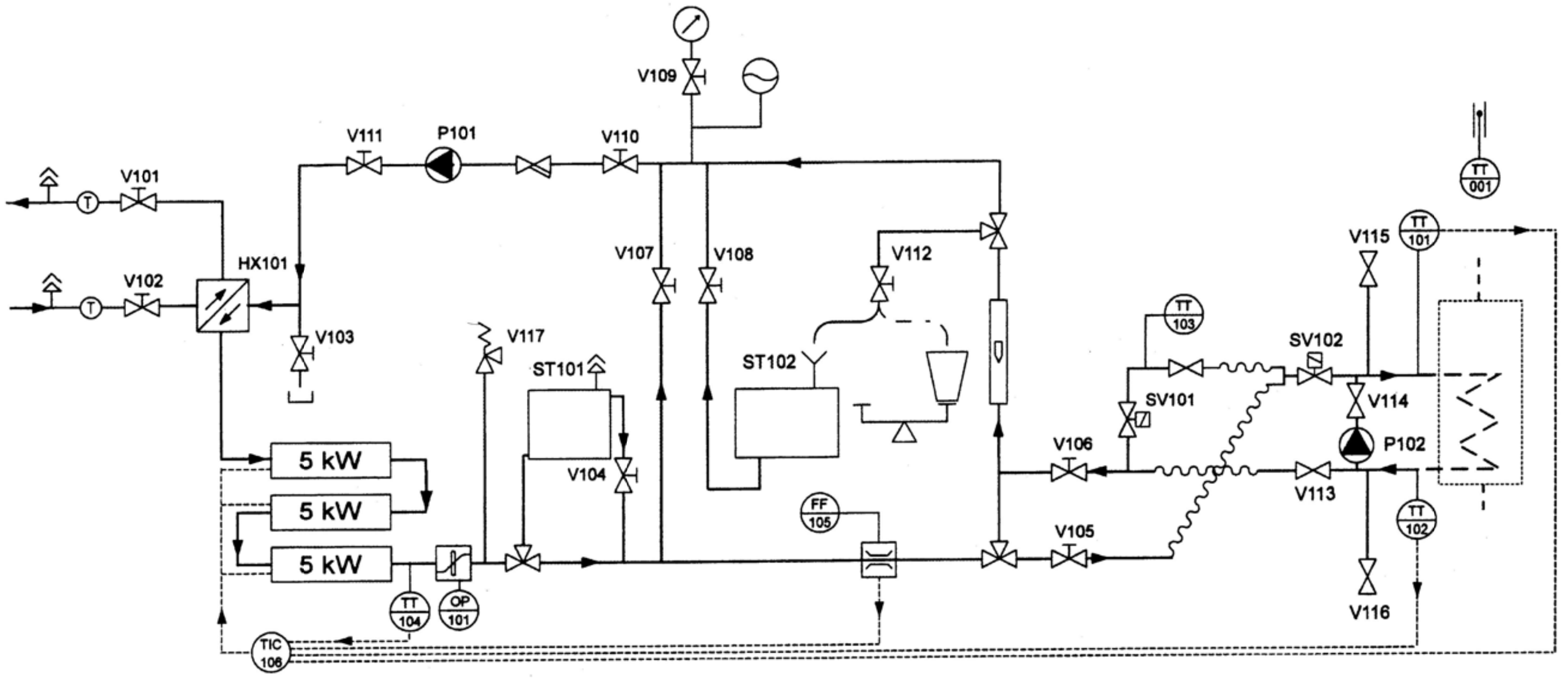
— The minimum heating power of the discharge circuit shall be 5 kW.

— The control deviation of the store inlet temperature shall be less than 0.05 K.

— The minimum heating up rate of the charge circuit with disconnected store shall be 3 K/min.

— The minimum available electrical heating power for electrical auxiliary heaters shall be 6.0 kW.

NOTE 3 The electrical power of the pump (P102) shall be chosen in such a way that the temperature increase induced by the pump (P102) is less than 0.6 K/h when the charge circuit is "short circuited" and operated at room temperature, ("short circuited" means that no storage device is connected and SV102, V113, V115and V116 are closed, see Figure 1).



Key	
FF	Flow meter
HX	Heat exchanger
OP	Overheating protection
P	Pump

Key	
ST	Store
SV	Solenoid valve
TT	Temperature sensor
TIC	Temperature indicator and controller
V	Valve

Figure 1 — Charge circuit of the store testing stand

The heating medium water in the charge circuit (see Figure 1) is pumped through the cooler (HX101) and the temperature controlled heaters (TIC106) by the pump (P101). A buffer tank (ST101) is used to balance the remaining control deviations. By means of the bypass (V107) the flow through the store can be regulated, it also ensures a continuously high flow through the heating section and therefore good control characteristics. With the solenoid valve (SV101) the heating medium can bypass the store to prepare a sudden increase of the inlet temperature into the store.

The temperature sensors are placed near the inlet (TT101) and outlet (TT102) connections of the store, the connection to the store is established through insulated flexible pipes.

The charge circuit can be operated closed, under pressure (design pressure 2.5 bar, membrane pressure expansion tank and pressure relief valve (V109)) as well as open(valve (V108) open) with the tank (ST102) serving as an expansion tank. A calibration of the installed flow meter (FF105) is possible by weighing the mass of water leaving the valve (V112). The installation is equipped with the usual safety devices, i.e., pressure relief valve (V117) and overheating protection device (OP101).

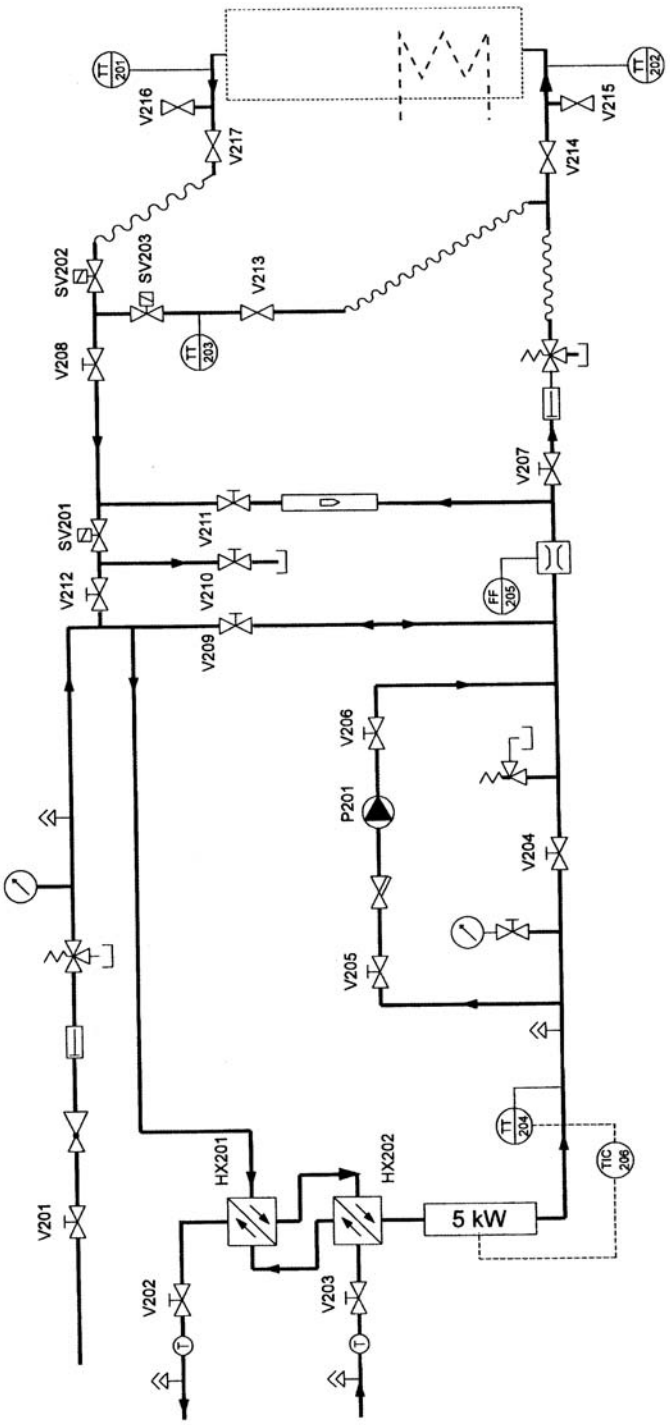
The discharge circuit (see Figure 2) is constructed in a similar way. It includes two coolers — (HX201) and (HX202) — and a temperature controlled heating element (TIC206) with 5 kW heating power. The discharge circuit can either be operated in open circulation with water from the net or it can be operated in closed circulation. During open operation the water is led via the safety equipment (V201) and flows through the coolers, the heating section and the flow meter (FF205) into the store. The hot water leaving the store flows through the solenoid valve (SV201) and the valve (V210) into the drain. The valve (V212) is closed.

For heating the water it is recommended to increase the flow through the heating section with the pump (P201) in order to improve the control performance; the additional volume flow returns through the bypass (V209).During closed-circle operation, the valve of the safety equipment and the cut-off valve (V210) remain closed, the valve (V212) is open and the water is circulated by the pump (P201).

NOTE 4 For periodical checks of the measuring accuracy, it is recommended to integrate a reference heater into the testing stand. Instead of a store, this reference heater is connected to the testing stand. The reference heater is supplied with an electric heating device.

NOTE 5 See [2] and [3] in Bibliography for further information on the use of reference heaters.

The heat transfer fluid used for testing may be water or a fluid recommended by the manufacturer. The specific heat capacity and density of the fluid used shall be known with an accuracy of 1 % within the range of the fluid temperatures occurring during the tests.



Key

FF	Flow meter	SV	Solenoid valve
HX	Heat exchanger	TT	Temperature sensor
P	Pump	TIC	Temperature indicator and controller
		V	Valve

Figure 2 — Discharge circuit of the store testing stand

6.1.2 Measuring data and measuring procedure

The data listed in Table 2 shall be measured with the given accuracy:

Table 2 — Measuring data

Measuring data	Measuring device (see Figure 1 and 2)	Uncertainty
volume flow V_C in the charge circuit between 0.05 m^3/h and 1 m^3/h	FF105	2.0 %
volume flow $\dot{V}_C$ in the discharge circuit between 0.05 m^3/h and 1 m^3/h	FF205	2.0 %
temperature $\vartheta_{C,i}$ of the charging medium at store inlet	TT101	0.1 K
temperature $\vartheta_{C,0}$ of the charging medium at store outlet	TT102	0.1 K
difference in the charging medium temperature $\Delta\vartheta_C$ between store inlet and store outlet: (for tests according to 6.3.1)	TT101 andTT102	0.02 K
difference in the charging medium temperature $\Delta\vartheta_C$ between store inlet and store outlet: (for tests according to 6.3.2)	TT101 andTT102	0.05 K
temperature $\vartheta_{D,i}$ of the discharging medium at store inlet	TT201	0.1 K
temperature, $\vartheta_{D,0}$ of the discharging medium at store outlet	TT202	0.1 K
difference in the discharging medium temperature $\Delta\vartheta_D$ between store inlet and store outlet: (for tests according to 6.3.1)	TT201 and TT202	0.02 K
difference in the discharging medium temperature $\Delta\vartheta_D$ between store inlet and store outlet: (for tests according to 6.3.2)	TT201 and TT202	0.05 K
ambient temperature ϑ_{am}	TT001	0.1 K
electric power $\dot{Q}_{el}$ (auxiliary heating)	-	2%

The relevant data shall be measured every 10 s at least and the measured data shall be recorded as mean values of at most three measured values. However, for Test H (see 6.3.1.1.3) during the transient the temperatures shall be measured and recorded every second.

The temperature sensors shall have a relaxation time of less than 10 seconds, (i.e., 90 % of the temperature variation is detected by the sensor immersed in the heat transfer fluid within 10 seconds after an abrupt step in the fluid temperature).

Prior to each store test a zero measurement should be performed where the fluid in the charge or discharge circuit is pumped over the short-circuited charge or discharge circuit. "Short-circuited" means that flow pipe and return pipe of the corresponding circuits are directly connected (recommended volume flow approximately 0,6 m3/h, temperatures 20 °C, 40 °C, 60 °C, 80 °C). If the measured temperature difference exceeds the permissible uncertainty of 0.02 K / 0.05 K, the temperature sensors shall be calibrated.

A reference heater may also be used for the zero measurement.

6.2 Installation of the store

6.2.1 Mounting

The store shall be mounted on the testing stand according to the manufacturer's instructions.

The temperature sensors used for measuring the inlet and outlet temperatures of the fluid used for charging and discharging the storage device, shall be placed as near as possible at least 200 mm to the inlet and outlet connections of the storage device. The installation of the temperature sensors inside the pipes shall be done according to approved methods of measuring temperatures

If there is/are more than one pair of charging and/or discharging inlet or outlet connections, then only one may be connected to the testing stand (at the same time) while the other(s) shall be closed.

The pipes between the store and the temperature sensors shall be insulated according to ISO 9774.

6.2.2 Connection

The way of connecting the storage device to the testing stand depends on the purpose of the thermal tests which shall be performed. Detailed instructions are given in the clauses where the thermal tests are described. Except the test described under 6.3.1.1.2, only the thermal performance of the storage device itself (excluding connecting pipes) is determined. Hence, for these tests the connections at the storage device, as delivered by the manufacturer, are considered as the thermal demarcation between the storage device and the testing stand.

Except the test described under 6.3.1.1.2, the solenoid valves shall be placed as nearer as possible to the inlet and outlet connections of the storage device.

Connections of the store which do not lead to the charge or discharge circuit of the testing stand shall be closed, and not connected heat exchangers shall be filled up 'with water. All closed connections shall be insulated in the same way as the store. Since fluid in closed heat exchangers expands with increasing temperature, a pressure relief valve shall be mounted.

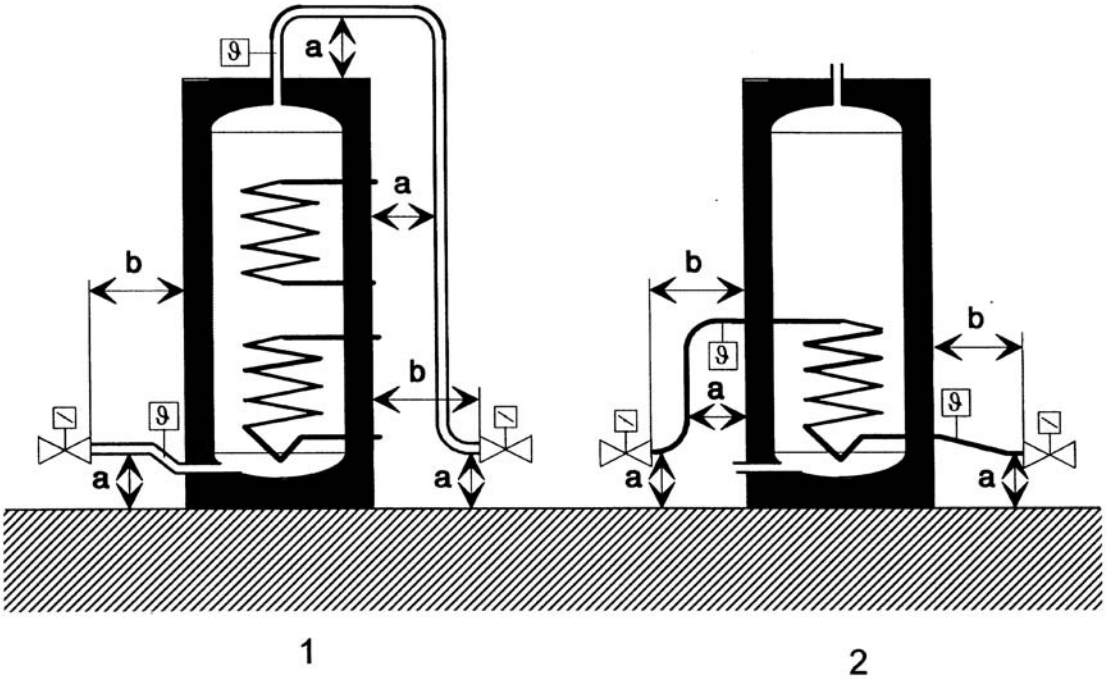
6.2.3 Testing of the storage device in respect of the design of the connections

The aim of the test described under 6.3.1.1.2, is to determine the influence of poor designed store connections on the heat loss of the store (e.g. due natural convection within one single pipe). For this test, the pipes connected to the store shall be taken into consideration, and convection flows may not be stopped near to the storage device by solenoid valves. Hence, for the test according to 6.3.1.1.2, the store shall be mounted in the following manner:

Each charge and discharge connection shall be carried out with pipes as shown in Figure 3.

If not specified in the manufacturer's instruction, the nominal diameter of the piping between the store and the valves shall be equal to the nominal pipe diameter of the store connections. The insulation shall be according to the reference conditions as specified in annex B of KS 1852-2 and annex A of KS 1855-2.

a = 100 mm
b = 1.5 *a



Key
1 Connecting of the connections for direct charge/discharge

2 Connecting of the heat exchangers

Figure 3 — Charge and discharge pipe connections

6.3 Test and evaluation procedures

The aim of store testing as specified in this Kenya Standard, is the determination of parameters required for the detailed description of the thermal behaviour of a hot water store. Therefore, a mathematical computer model for the store is necessary. The basic requirements on suitable models are specified in annex A and annex B.

The following parameters shall be known for the simulation of a store being part of a solar system:

a) Stored water:

- Height
- Effective volume respectively effective thermal capacity
- Heights of the inlet and outlet connections
- Heat loss capacity rate of the entire store

- If the insulation varies for different heights of the store, the distribution of the heat loss capacity rate should be determined for the different parts of the store.
- A parameter describing the degradation of thermal stratification during stand-by

NOTE 1 One possible way to describe this effect in a store model is the use of a vertical thermal conduction. In this case the corresponding parameter is an effective vertical thermal conductivity.

NOTE 2 An additional parameter may be used to describe the influence of different draw-off flow rates on the thermal stratification inside the store, if this effect is relevant.

- Positions of the temperature sensors (e. g. the sensors of the collector loop and auxiliary heater control)

b) **Heat exchangers:**

- Heights of the inlet and outlet connections
- Volume
- Heat transfer capacity rate as a function of temperature
- Information on the capacity in respect of stratified charging

NOTE 3 The capacity in respect of stratified charging can be determined from the design of the heat exchanger as well as from the course in time of the heat exchanger inlet and outlet temperatures.

- Heat loss rate from the heat exchanger to the ambient (necessary only for mantled heat exchangers and external heat exchangers)

c) **Electrical auxiliary heat source:**

- Position in the store
- Axis direction of heating element (horizontal or vertical). If the auxiliary heater is installed in a vertical way, also its length is required
- effectivity that characterizes the fraction of the thermal converted electric power which is actually transferred inside the store.

NOTE 4 Badly designed electrical auxiliary heaters may cause significant heat losses during operation. In this case the electrical power supplied to the heater is not equal to the thermal energy input to the store.

The following clauses describe the way, how the listed parameters can be determined. Therefore, specific test sequences are necessary. The test sequences indicated by letters (e. g. TEST A) can be subdivided into phases indicated by a number (e.g. A1 -conditioning). Between the end of one phase and the start of the following phase, a maximum stand-by time of 10 minutes is allowed. During this stand-by time the ambient temperature only shall be measured and recorded.

NOTE 5 One essential point of the described methods is that measurements inside the store are avoided.

NOTE 6 The determination of all above listed store parameters is possible only according to the method described under 6.3.2. However, some of the parameters may also be determined according to the method described under 6.3.1.

6.3.1 Determination of thermal capacity, heat loss capacity rate of the entire store and the heat transfer capacity rate of immersed heat exchangers by means of analytical energy and power balances

6.3.1.1 General

This clause describes the determination of the store thermal capacity and the store heat loss capacity rate by the classical methods of the European Solar Storage Jesting Group (SSTG) (see [2] in Bibliography).

NOTE The method for the determination of the heat transfer capacity rate of immersed heat exchangers is adopted from [4] (see Bibliography).

The thermal test sequences shall be carried out for the different groups of stores (see Table 1).

6.3.1.1.1 Determination of the thermal capacity and operating heat loss capacity rate of the entire store without pipe connections (TEST A)

This test shall be carried out for all groups of storage devices. The storage device shall be connected to the testing stand according to 6.2. The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand. The connections that enable a complete charge of the store shall be fitted to the charge circuit of the testing stand.

For stores according to group 2 and group 4 the lowest heat exchanger will usually be used for charging. If there exists a dead volume beneath this heat exchanger, problems will occur when steady-state is reached. In that case, the heat loss capacity rate cannot be determined by Test A.

— Test phase A1: conditioning until steady-state is reached

— Test phase A2: charge until steady-state is reached + 12 hours

— Test phase A3: discharge until steady-state is reached

Table 3 — Flow rates and store inlet temperatures for Test

Test		Charge circuit			Discharge circuit		
phase	process	$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C},i}$ °C	$\tilde{\vartheta}_{\mathrm{C},0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{V}_{\mathrm{D,i}}$ °C	$\tilde{\vartheta}_{\mathrm{D},0}$ °C
A1	conditioning	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable
A2	charge	0.25 × $\dot{v}_{\mathrm{n}}$	60.00	variable	0	—	—
A3	discharge	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable

6.3.1.1.2 Determination of stand-by heat loss capacity rate of the entire store with pipes (TEST AP)

This test shall be carried out for all groups of storage devices.

The goal of this test is to determine the heat loss capacity rate during stand-by. However, the influence of poorly designed connections on the heat loss capacity rate can also be determined if the heat loss capacity rates determined according to Test A and Test AP are compared.

The storage device shall be connected to the testing stand according to 6.2.1 and 6.2.3.

The connections that enable a complete discharge of the store shall be connected to the discharge circuit of the testing stand.

The joins which enable a complete charge of the store shall be connected to the charge circuit of the testing stand.

For stores according to group 2 and group 4, the lowest heat exchanger will usually be used for charging. If there exists a dead volume beneath this heat exchanger, problems will occur when steady-state is reached. In that case, the heat loss capacity rate cannot be determined by Test AP.

Test phase AP1:	conditioning until steady state-is reached
Test phase AP2:	charge until steady-state is reached + 12 hours
Test phase APS:	48 h stand-by
Test phase AP4:	discharge until steady-state is reached

Table 4 — Flow rates and store inlet temperatures for Test AP

Test phase	**Process**	**charge circuit**			**Discharge circuit**		
		$\tilde{\dot{V}}_C$ **l/h**	$\tilde{\vartheta}_{c,i}$ **°C**	$\tilde{\vartheta}_{c,0}$ **°C**	$\tilde{\dot{v}}_D$ **l/h**	$\tilde{\vartheta}_{D,i}$ **°C**	$\tilde{\dot{\vartheta}}_{D,i}$ **°C**
AP1	conditioning	0	—	—	0.5 x $\dot{V}_n$	20.00	variable
AP2	charge	0.25 × $\dot{v}_n$	60.00	variable	0	—	—
APS	stand-by	0	—	—	0	—	—
AP4	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.1.1.3 Determination of heat transfer capacity rate of immersed heat exchangers (TEST H).

The test procedure is based on a transient 2-sensor method using sensors $\vartheta_{C,i}$ and $\vartheta_{C,0}$. An abrupt and erratic temperature change is applied to the heat exchanger under test. The measurement of the store temperature is based on the temperature of the heat exchanger before the abrubt change of the fluid temperature. The heat transfer capacity rate of the heat exchanger is determined just after the end of the transient phase.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be connected to the discharge circuit of the testing stand. In order to reach a complete mixture and uniform store temperatures, the connection shall be carried out in such a way that hot water is drawn from the top of the store and supplied to its bottom.

The connections of the heat exchanger the heat transfer capacity rate of which shall be determined shall be connected to the charge circuit of the testing stand. The fluid shall flow through the heat exchanger as specified by the manufacturer.

The heat transfer fluid during the test shall be that specified by the manufacturer of the solar heating system. If no heat transfer fluid is specified by the manufacturer, water shall be used.

The following test conditions apply:

The flow rate in the heat exchanger shall be as specified by the manufacturer. If no flow rate is specified by the manufacturer, $\dot{V}_C = 1.2 \times \dot{V}_n$ shall be applied.

The heat transfer power applied to the heat exchanger during the test shall first be identical with the nominal one specified by the manufacturer ±10 %. Additional measurements shall be performed with half this power. If no heat transfer power is specified by the manufacturer, P_n and $0.5 \times P_n$ shall be used.

The temperature of the storage device close by the heat exchanger shall be uniform and successively adjusted to 60 °C, 50 °C, 40 °C, 30 °C, 20 °C, 10 °C with an uncertainty not greater than 1 °C.

a) Test phase H1: Initial conditioning

Heat up the whole storage device to 60 °C by means of the charge circuit, the discharge loop being operated as a mixing device as described above.

The heating up of the store may effected by any heating power. However, at the end of the conditioning the heating power shall be adjusted to the nominal heating power and the corresponding temperature at the outlet of the charge circuit, $\vartheta_{c,o,1}$ shall be noted for further reference (see below). For the monitoring of the conditioning, $\vartheta_{D,o.}$ shall be applied as temperature of the store.

In the final stage of conditioning, the heating/cooling unit of the discharge circuit may also be used to adjust more precisely the store temperature to 60 °C.

b) Test phase H2: Measurement of the heat transfer capacity rate at nominal heating power

Close SV102, open SV101 and V114, turn on P102 (see Figure 1 and 2) Switch off the discharge circuit pump (P201) to stop mixing operation.

Wait for steady-state conditions in the store, defined (only for this purpose) as $\left|\vartheta_{C,i} - \vartheta_{C,0}\right| < 0.05$ K and $\vartheta_{c,i}$ constant for the last 5 min with an uncertainty not exceeding 0.1 K.

Operate the charge circuit in the bypass mode at the under test phase H1 specified temperature $\vartheta_{c,0,1}$; wait for steady state conditions in the charge circuit.

Perform the temperature change by steps in the heat exchanger as follows:

- Assure that $\vartheta_{C,i}$ and $\vartheta_{C,0}$ are recorded with the time resolution of at least 1 s during the transient.
- Switch off P102 and close V114. Then quickly close SV101 and simultaneously open SV102.
- After the end of the transient, the measured data may be recorded slower again (see also 6.3.1.2.5 for more details).

NOTE 1 A typical duration of the transient is approximately 3 min.

To get a second independent measurement result, perform a second temperature step under the same conditions.

c) Test phase H3: Measurement of the heat transfer capacity rate at halved nominal heating power

Repeat the complete test phase H2 (two independent measurements) with a reduced temperature of the charge circuit (instead of $\vartheta_{C,0,1}$) in order to operate the heat exchanger at half nominal power.

d) Test phase H4: Conditioning at the next store temperature

Discharge the storage device in order to reduce its temperature by 10 K. Mix the store thoroughly by means of the discharge circuit.

e) **Test phase H5: Measurement of the heat transfer capacity rate at the new store temperature**

Repeat test phases H2 and H3 (four independent measurements, two at nominal and two at half nominal power).

NOTE 2 The temperature of the charge circuit which is necessary for the transmission of the required power is determined by trial and error based on the values used at the previous measurement steps. The overtemperature needed in the charge circuit is increasing when the store temperature decreases, as the increasing water viscosity leads to a decrease of the heat transfer capacity rates.

f) **Test phase H6 …. H9: Completion of the entire measurement sequence**

Repeat test phases H4 and H5 down to a store temperature up to 10 °C.

6.3.1.2 Evaluation of the test sequences according to 6.3.1.1 by means of analytical energy and power balances

This clause describes the evaluation of test A according to 6.3.1.1.1, test A according to 6.3.1.1.1 and test AP according to 6.3.1.1.2 and test H according to 6.3.1.1.3.

NOTE For the equations given for test evaluation and error analysis (equation (1) to (28)) see also [2] in Bibliography.

The test evaluation described in this clause determines three store parameters (thermal capacity of the entire store, operating heat loss capacity rate and stand-by heat loss capacity rate). To obtain these parameters, the time required to reach a steady state after an abrupt change of the inlet temperature and the store temperature shall be calculated using the measured data.

6.3.1.2.1 Calculation of the time required for a heat store to reach steady state after a abrupt change of the inlet temperature

For the estimation of the minimum time $t_{\mathrm{st,\ min}}$ required for a heat store to achieve steady state, the following four different limit cases are considered: a store with or without heat exchanger and with mixed or stratified characteristic during charge or discharge.

For a stratified store without heat exchanger, $t_{\mathrm{st,\ min}}$ is calculated by means of equation (1).

$$t_{\mathrm{st,\ min}} = 1.5 \times t_{\mathrm{fill}} \tag{1}$$

Where t_{fill}, is the time required for the exchange of one store volume.

The typical example of such a store is hot water store with direct discharge. A store of this type reaches steady-state conditions after 1.5 fill times at least.

For a stratified store with heat exchanger, equation (2) is used. The derivation of $t_{\mathrm{st,\ mix}}$ has been effected for the completely mixed store. Since quite some heatstores with heat exchanger which are praised as "stratified" behave, in reality, more or less mixed, the same criterion is here applied as for the completely mixed store. The factor 1.5 takes into account possible errors in respect of the estimation of the heat transfer capacity rate between the heat exchanger and the store $(UA)_{\mathrm{hx,s.}}$

In the course of a test, $(UA)_{\mathrm{hx,s}}$ is not constant. Especially by approaching steady-state conditions, its value generally decreases.

$$t_{\mathrm{st,min}} = 1.5 \times t_{\mathrm{st,mix}} \tag{2}$$

where $t_{\mathrm{st\ mix}}$ is determined from equation (6).

For a completely mixed store with heat exchanger, $t_{\mathrm{st,\ min}}$ is also calculated from equation (2).

For a fully mixed store without heat exchanger (where there is no uncertainty with respect to $(UA)_{\mathrm{hx,s},\ \varepsilon\,=\,1}$), equation (3) applies.

$$t_{\mathrm{st,min}} = 1.5 \times t_{\mathrm{st,mix}} \qquad (3)$$

After the period $t_{\mathrm{st,\ mix}}$ the heat flow supplied to a fully mixed store (which actually reaches steady-state conditions after infinite time) is less than 1.05 times the heat flow emitted from the store In that case the error in $(UA)_{\mathrm{s,a}}$ due to insufficiently reached steady-state conditions is less than 5 % (equation (4)).

$$\begin{aligned}\dot{Q}_{\mathrm{H}} &= \dot{V}\times\rho\times c_{\mathrm{p}}\times\left(\vartheta_{\mathrm{i}}-\vartheta_{\mathrm{e}}\right) < 1.05\times(UA)_{\mathrm{s,a}}\times\left(\vartheta s(t_{\mathrm{st,mix}})-\vartheta_{\mathrm{a}}\right)\\ &= \dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon\times\left(\vartheta_{\mathrm{i}}-\vartheta_{\mathrm{s}}\left(t_{\mathrm{st,mix}}\right)\right) < 1.05\times(UA)_{\mathrm{s,a}}\times\left(\vartheta_{\mathrm{s}}\left(t_{\mathrm{st,mix}}\right)-\vartheta_{\mathrm{a}}\right) \qquad (4)\end{aligned}$$

For tests where the store is discharged up to the ambient temperature, the right member of equation (4) can become very small, leading to large values for $t_{\mathrm{st,\ mix}}$ that may exceed the time which is available for the test. In those cases a default value of $(UA)_{\mathrm{s,a}}$ should be used.

The store temperature, $\vartheta_{\mathrm{s}}(t)$ can for a completely mixed store with heat exchanger ($(UA)_{\mathrm{hx,s}}$ = constant) be calculated from equation (5).

$$\vartheta_{\mathrm{s}}(t) = \mathrm{k}_0 + \left(\vartheta_{\mathrm{s}}(t_0) - K_0\right)\times \mathrm{e}^{-\mathrm{k}_2\times xt} \qquad (5)$$

Where $$\mathrm{k}_0 = \frac{\dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon\times\vartheta_{\mathrm{i}} + (UA)_{\mathrm{s,a}}\times\vartheta_{\mathrm{a}}}{\dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon + (UA)_{\mathrm{s,a}}}$$

and $$\mathrm{k}_2 = \frac{\dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon + (UA)_{\mathrm{s,a}}}{C_{\mathrm{s,m}}}$$

Where

t_0 is the time at which the step with the heat exchanger effectiveness occurs.

$$\varepsilon = 1 - e^{-NTU}$$

$t_{\mathrm{st,mix}}$ is obtained by substitution of $\vartheta_{\mathrm{s}}(t)$ in equation (4) and conversion (equation (6)).

$$t_{\mathrm{st,mix}} = \frac{1}{k_2}\times\ln\left[\frac{\vartheta_{\mathrm{s},1} - k_0}{k_1 - k_0}\right] \qquad (6)$$

where $$\mathrm{k}_1 = \frac{\dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon\times\vartheta_{\mathrm{i},2} + 1.05\times(UA)_{\mathrm{s,a}}\times\vartheta_{\mathrm{a}}}{\dot{V}\times\rho\times c_{\mathrm{p}}\times\varepsilon + 1.05\times(UA)_{\mathrm{s,a}}}$$

6.3.1.2.2 Estimation of the store temperature

The store temperature which is estimated for determination of $C_{\mathrm{s,m}}$ and $(UA)_{\mathrm{s,a}}$ shall be accurate especially under steady-state conditions. As $(UA)_{\mathrm{s,a}}$ is based on the difference between the temperatures of the store and the ambient, the store temperature is also needed for the calculation of the heat losses during the transient between two steady-state conditions. As the store temperature generally increases or decreases rapidly (75 % to 80 % of the step are already reached after 2 or 3 exchanges of the storage fill), a greater error in 5S during the transient can be accepted as it will not affect significantly the total heat loss between two steady-states and, consequently, $\mathrm{C}_{\mathrm{s,\ m}}$.

As in 6.3.1.2.1, also here a distinction has been made according to the four types of stores.

For a stratified store without heat exchanger, ϑ_S is estimated from equation (7) for the steady state and from equation (8) during the transient.

$$\vartheta_s = \frac{\vartheta_i + \vartheta_c}{2} \qquad (7)$$

$$\vartheta_s = \frac{\vartheta_{i,1} + \vartheta_{c,1}}{2} + t_H \times \left[\frac{\vartheta_{i,2} + \vartheta_{2,2}}{2} - \frac{\vartheta_{i,1} + \vartheta_{c,1}}{2} \right] \qquad (8)$$

with $t_H = \frac{t - t_0}{t_{cf}}$, if $t_H < 0$, $t_H = 0$ and if $t_H > 1$, $t_H = 1$.

where

t_0 time at which step occurs

The maximal possible error in ϑ_S from equation (7) is

$$\delta\vartheta_s = \frac{\delta\vartheta_i + \delta\vartheta_c}{2} \qquad (9)$$

As stated above, the error in ϑ_S during the transient can be neglected.

For a stratified heat store with heat exchanger, the store temperature can be estimated from equation (10) and the error in ϑ_s from equation (11).

$$\vartheta_s = \frac{\vartheta_i + \vartheta_c}{2} - \frac{\Delta\vartheta_{i,c}}{NTU} \qquad (10)$$

$$\frac{\delta\vartheta_s = \delta\vartheta_c}{2} + \frac{\delta\Delta\vartheta_{i,e}}{NTU} + \frac{\delta NTU x \delta\Delta_{i,e}}{NTU^2} \qquad (11)$$

For a completely mixed store with heat exchanger, the store temperature can be estimated from equation (12) and the error from equation (13).

$$\vartheta_s = \vartheta_i - \frac{\Delta\vartheta_{i,e}}{1 - e^{-NTU}} \qquad (12)$$

$$\delta\vartheta_s = \delta\vartheta_i + \frac{\delta\Delta\vartheta_{i,e}}{1 - e^{-NTU}} + \delta NTU \times \Delta\vartheta_{i,e} \mathrm{x} \frac{e^{-NTU}}{\left(1 - e^{-NTU}\right)^2} \qquad (13)$$

To avoid physically impossible values of the store temperature ($\vartheta_s < \vartheta_{s,1}$) due to underestimation of $(UA)_{hx,s}$ and during the residence time of the heat transfer fluid in the heat exchanger, in all cases where $\vartheta_s < \vartheta_{s,1}$ calculated, $\vartheta_s = \vartheta_e$ is set in the evaluation.

For a fully mixed store without heat exchanger (NTU = ∞), equation (12) gives:

$$\vartheta_{\mathrm{s}} = \vartheta_{\mathrm{e}} \tag{14}$$

and

$$\delta\vartheta_{\mathrm{s}} = \delta\vartheta_{\mathrm{e}} \tag{15}$$

6.3.1.2.3 Determination of the operating heat loss capacity rate $(UA)_{\mathrm{op,s,a}}$

The operating heat loss capacity rate $(UA)_{\mathrm{op,s,a}}$ is determined under steady-state conditions from equation (16) over a period of t_{L} (it is recommended to use t_{L} = 16 h).

$$(UA)_{\mathrm{op,s,a}} = \frac{1}{t_{\mathrm{L}}} \times \int_{t_{st}}^{t_{\mathrm{st}}+t_{\mathrm{L}}} \frac{\dot{V} \times \rho \times c_{\mathrm{p}} \times d\vartheta_{\mathrm{i,e}}}{\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}} \times dt \tag{16}$$

where

t_{st} time after which the store has reached steady state.

The error of $(UA)_{\mathrm{s,a}}$ is calculated by equation (17):

$$\delta(UA)_{\mathrm{op,s,a}} \times \left[\frac{\delta\rho}{\rho} + \frac{\delta c_{\rho}}{c_{\mathrm{p}}} + \frac{\delta\Delta\vartheta_{\mathrm{i,e}}}{\Delta\vartheta_{\mathrm{i,e}}} + \frac{\delta\nu}{\nu} + \frac{\delta\vartheta_{\mathrm{a}}}{\left|\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}\right|} + \frac{\delta\vartheta_{\mathrm{s}}}{\left|\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}\right|} \right] \tag{17}$$

Relative errors in the density and specific heat capacity of the water are neglected as well as the error in the measurement of the time t_{L}. Errors in inlet temperature, temperature difference across the store and flow rate depend on the individual test facility.

For the determination of the error in respect of the ambient temperature ϑ_{a}, not only the measurement error but also possible fluctuations of the ambient temperature shall be considered as these lead to uncertainties in $(UA)_{\mathrm{op,s,a}}$, too. It is obvious that short-time fluctuations of a few minutes do not influence the result as $(UA)_{\mathrm{op,s,a}}$ is calculated as a mean value over 16 hours. If there is a drift in the ambient temperature, the application of a mean ambient temperature leads, however, to a systematical error due to an insufficient steady-state.

It is neither possible nor sensible to include all possible changes in the error analysis, but rather certain requirements on the maximum allowable changes in 3a shall be specified. For the remaining deviations, a reasonable estimation that meets the following demands should be applied:

- simple and universally valid calculation,
- long-term drift is more important than short-term deviations.

Both requirements are met by the standard deviation of the ambient temperature; therefore, the additional error is estimated by means of the standard deviation in ϑ_{a} and the total uncertainty in ϑ_{a} can then be calculated by means of equation (18).

$$\delta\vartheta_{\mathrm{a,t}} = \delta\vartheta_{\mathrm{a}} \tag{18}$$

6.3.1.2.4 Determination of the thermal capacity C_{s} of the entire store

The net heating power supplied to the store is calculated by equation (19)

$$\dot{Q}_{\mathrm{S}} = \dot{V} \times \rho \times c_{\mathrm{p}} \times \Delta\vartheta_{\mathrm{i,e}} - (UA)_{\mathrm{s,a}} \times (\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}) \tag{19}$$

The net heating power removed from the store is calculated by equation (20)

$$\dot{Q}_{\mathrm{S}} = \dot{V} \times \rho \times c_{\mathrm{p}} \times \Delta\vartheta_{\mathrm{i,e}} + (UA)_{\mathrm{s,a}} \times (\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}) \qquad (20)$$

The measured net store heat input or output during the time (equation (21)) is obtained by integration of equation (19) or (20)

$$Q_{\mathrm{S,m}}(t_{\mathrm{x}}) = \int_{to}^{t_x} \dot{Q}s \times dt \qquad (21)$$

The measured store capacity $C_{\mathrm{s,m}}$ is the difference between the amounts of heat at one steady-state (store temperature $\vartheta_{\mathrm{s,1}}$) and another one (store temperature $\vartheta_{\mathrm{s,2}}$) divided by the change in store temperature (equation (22)).

$$C_{\mathrm{s,m}} = \frac{1}{\vartheta_{\mathrm{s,2}} - \vartheta_{\mathrm{s,1}}} \times \int_{to}^{t_{\mathrm{st,min}}} \dot{Q}_{\mathrm{s}} \times dt = \frac{Q_{\mathrm{s,m}}\left(t_{\mathrm{st,min}}\right)}{\vartheta_{\mathrm{s,2}} - \vartheta_{\mathrm{s,1}}} \qquad (22)$$

NOTE In this Kenya Standard, the total heat amount supplied to the store is counted positive and the total heat amount extracted from the store or transferred (lost) to the ambient is counted negative.

The error in the net amount of heat supplied to the store at charge (x=C) or extracted from the store at discharge (x=D) is calculated from

$$\delta\dot{Q}_{\mathrm{S}} = \left[(\delta\dot{Q}_{\mathrm{S,X}})^2 + (\delta\dot{Q}_{\mathrm{s,a}})^2\right]^{0.5} \qquad (23)$$

where

$$\delta\dot{Q}_{\mathrm{s,x}} = \dot{Q}_{\mathrm{S}} \times \left[\frac{\delta\rho}{\rho} + \frac{\delta c_{\mathrm{p}}}{c_{\mathrm{p}}} + \left|\frac{\delta\Delta\vartheta_{\mathrm{i,e}}}{\Delta\vartheta_{\mathrm{i,e}}}\right| + \frac{\delta\dot{V}}{\dot{V}}\right]$$

$$\delta\dot{Q}_{\mathrm{S,2}} = \delta(UA)_{\mathrm{s,a}} \times \left(\vartheta_{\mathrm{s}} - \vartheta_{\mathrm{a}}\right) + (UA)_{\mathrm{s,a}} \times \left(\delta\vartheta_{\mathrm{s}} - \delta\vartheta_{\mathrm{a}}\right)$$

If $(UA)_{\mathrm{s,a}}$ has been determined at steady-state conditions after or before a temperature change by steps, it can be assumed that the errors in the heat loss capacity rate and the heat input to the store under steady-state conditions are approximately equal. Hence, the error in the net heat input to the store is approximately equal to the error in the heat loss of the store. In that case one of the two factors in equation (23) can be neglected.

The error in the net heat input to the store is given by

$$\delta Q_{\mathrm{s,m}}\left(t_{\mathrm{c}}\right) = \int_{to}^{t_x} \delta Q_{\mathrm{s}} \times dt \qquad (24)$$

The error in the measured store capacity is determined by the following equation:

$$\delta C_{\mathrm{s,m}} = C_{\mathrm{s,m}} \times \left[\left|\delta Q_{\mathrm{s,m}}\right| + \left|\frac{\delta \vartheta_{\mathrm{s,1}}}{\vartheta_{\mathrm{s,2}} - \vartheta_{\mathrm{s,1}}}\right| + \left|\frac{\delta \vartheta_{\mathrm{s,2}}}{\vartheta_{\mathrm{s,2}} - \vartheta_{\mathrm{s,1}}}\right| \right] \qquad (25)$$

The temperature difference required between two steady states can be provided by charging or discharging the store. Regarding Test A as described under 6.3.1.1, the store capacity C_s can be determined twice, i.e. from the charge test (test phase A2) and from the discharge test (test phase A3).

Theoretically, it can be assumed, that the thermal capacity of the entire store determined from a charge test ($C_{s.C}$) is equal to the thermal capacity of the entire store determined from a discharge test ($C_{s,D}$). In reality there will be a differencebetween both capacities, due to measurement and evaluation errors. Hence this test sequence enables also a check of the measurement technique and the evaluation method. If the difference between $C_{s,C}$ and $C_{s,D}$ exceeds 3 % (related to the mean value of $C_{s,C}$ and $C_{s,D}$) the test is not valid.

The thermal capacity of the entire store C_s is calculated by the following equation:

$$C_s = \frac{C_{\mathrm{s,c}} + C_{\mathrm{s,D}}}{2} \qquad (26)$$

6.3.1.2.5 Determination of the stand-by heat loss capacity rate $(UA)_{sb,s,a}$

The heat loss of the store occurred during the stand-by period t_{sb} is calculated by equation (27)

$$Q_{\mathrm{l,sb}} = Q_{\mathrm{s1,m}} - Q_{\mathrm{s2,m}} \qquad (27)$$

Where

$Q_{s1,m}$ is the energy of the store at the start of the stand-by period

$Q_{s2,m}$ is the energy of the store at the end of the stand-by period.

$Q_{s1,m}$ and $Q_{S2,\,m}$ are calculated by equation (21).

The stand-by heat loss capacity rate is calculated by equation (28)

$$(UA)_{\mathrm{sb,s,a}} = -\frac{C_{\mathrm{s}}}{t_{\mathrm{sb}}} \cdot \ln\left(\frac{C_{\mathrm{s}}\left(\vartheta_{\mathrm{s1}} - \vartheta_{\mathrm{a,sb}}\right) - Q_{\mathrm{l,sb}}}{C_{\mathrm{s}}\left(\vartheta_{\mathrm{s1}} - \vartheta_{\mathrm{a,sb}}\right)}\right) \qquad (28)$$

where

C_s is the thermal capacity of the entire store calculated by equation (26)

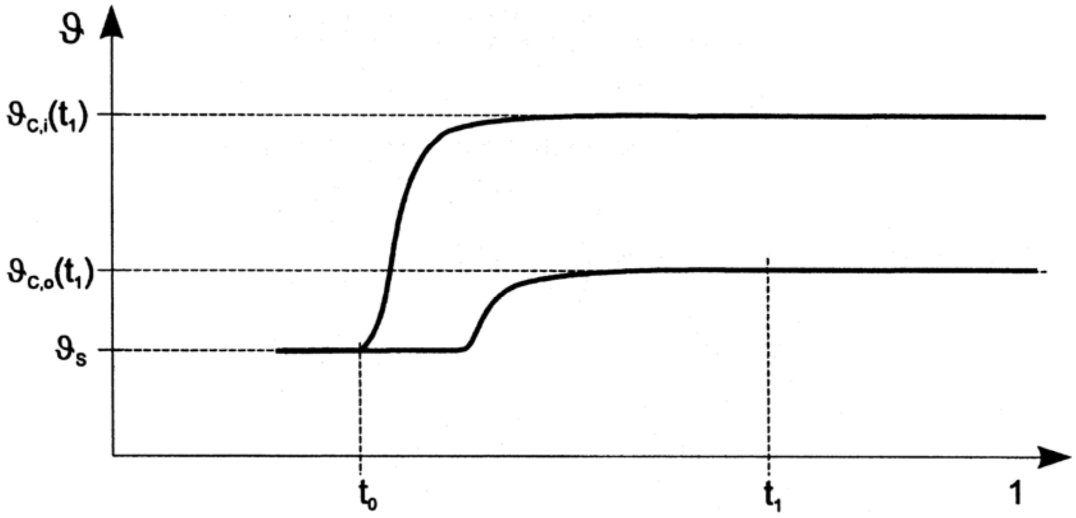
ϑ_{s1} is the store temperature at the start of the stand-by period

$\vartheta_{\mathrm{a,sb}}$ the average value of the ambient temperature over the stand-by period.

6.3.1.2.6 Determination of the heat transfer capacity rate of immersed heat exchangers

Figure 4 shows the temperature variations $\vartheta_{\mathrm{C,i}}$ and $\vartheta_{\mathrm{C,0}}$ observed before, during and after the transient described in test phase H2 (see 6.3.1.1.3). Two characteristic times are of importance: t_0, just before the transient, and as soon as a quasi-steady state with slow increase of all temperatures can be determined.

NOTE Typically $t_1 - t_0$ is approximately 1.5 min and the temperature increase of the heated store in this time interval is less than 2 % of $\Delta\vartheta_{\mathrm{m}}$. The mean logarithmic temperature difference is defined according to equation (29). For the smallest storage devices which are equipped with heat exchangers of high nominal power, the temperature increase is greater than 2 % of $\Delta\vartheta_{\mathrm{m}}$; these facts restrict the accuracy of the test procedure.



Key
1 Time

Figure 4–Temperatures $\vartheta_{\mathrm{C,i}}(t)$ and $\vartheta_{\mathrm{C,0}}(t)$ observed before, during and after the transient described in test phase H2

The store temperature near to the heat exchanger ϑ_{s} is $\vartheta_{\mathrm{C,i}}(t_0)$.. This temperature is also equal to $\vartheta_{\mathrm{C,0}}(t_0)$·

The mean logarithmic temperature difference of the heat exchanger is

$$\Delta\vartheta_{\mathrm{m}} = \frac{\vartheta_{\mathrm{C,i}}(t_1) - \vartheta_{\mathrm{C,0}}(t_1)}{\ln\left(\dfrac{\vartheta_{\mathrm{C,i}}(t_1) - \vartheta_{\mathrm{C,i}}(t_0)}{\vartheta_{\mathrm{C,0}}(t_1) - \vartheta_{\mathrm{C,i}}(t_0)}\right)} \qquad (29)$$

The heat transfer capacity rate of the heat exchanger is then

$$(UA)_{\mathrm{hx,s}} = \frac{\dot{m}_{\mathrm{C}} \times c_{\mathrm{p}}\left(\vartheta_{\mathrm{C,i}}(t_1) - \vartheta_{\mathrm{C,0}}(t_1)\right)}{\Delta\vartheta_{\mathrm{m}}} = \dot{m}_{\mathrm{C}} \times c_{\mathrm{p}} \times \ln\left(\frac{\vartheta_{\mathrm{C,0}}(t_1) - \vartheta_{\mathrm{C,i}}(t_0)}{\vartheta_{\mathrm{C,0}}(t_1) - \vartheta_{\mathrm{C,i}}(t_0)}\right) \qquad (30)$$

6.3.2 Determination of store parameters by means of parameter identification

The store is tested on the test stand by different specific test sequences. The sequences are specified so as to stimulate the physical effects which correspond to the parameter to be determined. The measuring data are evaluated by parameter identification program using a store model.

6.3.2.1 Test sequences

This clause describes the thermal test sequences for the different groups of stores.

6.3.2.1.1 General

In the following, the conditions are specified under which the stores shall be tested. An overview on the test sequences for determination of the different store parameters is given in Table 5

Table 5 —Compilation of the test sequences

Purpose of test	Test	Clause
Determination of the store volume, the heat transfer capacity rate of the lowest heat exchanger and the thermal stratification during discharge.	Test C group 1 group 2 group 3 group 4	 6.3.2.1.2.1 6.3.2.1.2.2 6.3.2.1.2.3 6.3.2.1.2.4
Determination of the thermal stratification during discharge with a 'high' flow rate	Test S	6.3.2.1.3
Determination of the heat loss capacity rate of the entire store during stand-by	Test L: group 1 group 2 group 3 group 4	 6.3.2.1.4.1 6.3.2.1.4.2 6.3.2.1.4.3 6.3.2.1.4.4
Determination of the heat transfer capacity rate and the position of the auxiliary heat exchanger(s)	Test NiA for stores with auxiliary heating elements	6.3.2.1.5
Determination of the position and length of the electrical heating element(s)	Test NiA for stores with electrical heating elements	6.3.2.1.6
Determination of the degradation of thermal strafication during stand-by	Test NiA and Test NiB for stores of group 1 and 3 Test NiA and Test NiB for stores Of group 2 and 4 Test EiA and Test EiB for stores with electrical auxiliary heating elements only.	6.3.2.1.7.1 6.3.2.1.7.1 6.3.2.1.5 6.3.2.1.7.2 6.3.2.1.6 6.3.2.1.7.3

NOTE 1 The exact vertical positions of the temperature sensors as well as the upper connections of the heat exchangers above which the store is charged mixedly, have a minor influenceon the thermal behaviour of the store. Hence these vertical positions need not to be determined by means of parameter identification. It is recommended to measure the corresponding positions or to determine them from the drawing of the store.

The following applies to all tests for determination of the heat transfer capacity rate of the heat exchangers:

The flow rates through the heat exchangers as well as the heating powers which are given for the determination of the heat transfer capacity rate (dependent on temperature) of the heat exchangers are recommendations. Other flow rates and heating powers may also be used, if they better correspond to the real operating conditions or are specified in the manufacturers instruction. This shall, however, be specified in the test report.

NOTE 2 The heat transfer capacity rate of immersed heat exchangers is increasing with the mean local temperature (the water becomes more dilute), the transmitted heating power and the flow rate through the heat exchanger. Therefore, different results for different operating conditions are expected.

6.3.2.1.2 Determination of the store volume, the heat transfer capacity rate of the lowest heat exchanger and the thermal stratification during discharge (TEST C)

The store volume determined by the method described below is the effective store volume.

NOTE For stores with a dead volume, the effective thermal capacity determined according to 6.3.1.1 is greater than the store volume, or the thermal capacity of the entire store, determined according to this clause. This effect is to be explained by the long charging period which is necessary to achieve steady-state conditions and during which the fluid in the dead volume is heated due to heat conduction. During usual operation, no heat is stored in the dead volume. Hence, for stores with a dead volume, the effective store volume is less than the store volume measured in litres. The effective store volume may be determined by a test sequence by means of which it is not intended to reach steady-state conditios.

The heat transfer capacity rate of the heat exchangers refers to heat exchangers which are not separated from the storage device.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the store shall be fitted to the charge circuit of the testing stand.

6.3.2.1.2.1 Group 1

The goal of this test is the determination of the effective store volume and the thermal stratification during discharge with a relatively 'low' flow rate.

Test C (group 1):

- Test phase C1: conditioning until steady-state is reached
- Test phase C2: charging until 3Co = 55 °C
- Test phase C3: discharging until steady-state is reached

Table 6 — Flow rates and store inlet temperatures for Test C (group 1)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\vartheta_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
C1	conditioning	0	—	—	0.5 x $\dot{v}_{n}$	20.00	variable
C2	charge	0.5 x $\dot{v}_{n}$	60.00	variable	0	—	—
C3	discharge	0	—	—	0.5.× $\dot{v}_{n}$	20.00	variable

6.3.2.1.2.3 Group 2

The goal of this test is the determination of the effective store volume, the heat transfer capacity rate of the charge heat exchanger and the stratification during discharge with a relatively 'low' flow rate.

Test C (group 2):

- Test phase C1: conditioning until steady-state is reached
- Test phase C2: charge with constant charge power of $P_c = 1.0 \cdot P_n$ until $\vartheta_{C,0} = 60$ °C
- Test phase C3: discharge until steady-state is reached

Table 7 — Flow rates and store inlet temperatures for Test C (group 2)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\vartheta_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
C1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
C2	charge	1.2 × $\dot{v}_n$	60.00	variable	0	—	—
C3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.2.1.2.3 Group 3

Test C (group 3):

- Test phase C1: conditioning until steady-state is reached
- Test phase C2: charge until $\vartheta_{C,0}$ = 55 °C
- Test phase C3: discharge until steady-state is reached

Table 8 — Flow rates and store inlet temperatures for Test C (group 3)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
C1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
C2	charge	0.5 × $\dot{v}_n$	60.00	variable	0	—	—
C3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.2.1.2.4 Group 4

The goal of this test is the determination of the effective store volume and the heat transfer capacity rate of the discharge heat exchanger with a relative 'low' flow rate.

The thermal stratification during discharge can, of course, only be assessed if the store is discharged stratified

Test C (group 4):

- Test phase C1: conditioning until steady-state is reached
- Test phase C2: charge with constant charge power of $\tilde{P}_C = 1.0 \times \tilde{P}_n$ until $\vartheta_{C,0}$ = 60 °C.
- Test phase C3: discharge until steady-state is reached

Table 9 — Flow rates and store inlet temperatures for Test C (group 4)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
C1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
C2	charge	1.2 × $\dot{v}_n$	variable	variable	0	—	—
C3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.2.1.3 Determination of the thermal stratification during discharge with a 'high1 flow rate (TEST S)

For some stores of group 1 and 2, the thermal stratification during discharge and/or the draw off profile (plotted over the number of the withdrawn store volumes) may depend on the draw off flow rate. The goal of this test is to determine the thermal stratification during discharge with a 'high' flow rate.

Test S shall only be performed when it is determined by Test C that the store is discharged stratified.

Test S:

According to Test C specified in 6.3.2.1.2, but with a discharge flow rate of $\dot{V}_D = \dot{V}_n$, but not less than 600 l/h.

6.3.2.1.4 Determination of the stand-by heat loss capacity rate of the entire store (TEST L)

The goal of this test is the determination of the heat loss capacity rate of the entire store during stand-by. Under consideration of note 2 in 6.3.2.1, the same operating conditions for the heat exchanger as in Test **C** shall be used.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the store shall be fitted to the charge circuit of the testing stand.

6.3.2.1.2.1 Group 1

Test L:

- Test phase L1: conditioning until steady-state is reached
- Test phase L2: charge until , $\vartheta_{C,0}$ =55 °C
- Test phase L3: 48 hours stand-by
- Test phase L4: discharge until steady-state is reached

Table 10 — Flow rates and store inlet temperatures for Test L (group 1)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,0}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{\mathrm{D,0}}$ °C
L1	conditioning	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable
L2	charge	0.5 × $\dot{v}_{\mathrm{n}}$	60.00	variable	0	—	—
L3	stand-by	0	—	—	0	—	—
L4	discharge	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable

6.3.2.1.4.2 Group 2

Test L:

- Test phase L1: conditioning until steady-state is reached
- Test phase L2: charge with constant charge power of $\tilde{P}_{\mathrm{C}} = 1.0 \times \tilde{P}_{\mathrm{n}}$ until $\vartheta_{\mathrm{C,0}}$ = 60 °C
- Test phase L3: 48 hours stand-by
- Test phase L4: discharge until steady-state is reached

Table 11 — Flow rates and storage device inlet temperatures for Test L (group 2)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,0}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{\mathrm{D,0}}$ °C
L1	conditioning	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable
L2	charge	0.5 × $\dot{v}_{\mathrm{n}}$	60.00	variable	0	—	—
L3	stand-by	0	—	—	0	—	—
L4	discharge	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable

6.3.2.1.4.3 Group 3

Test L:

- Test phase L1: conditioning until steady-state is reached
- Test phase L2: charge until $\vartheta_{\mathrm{C,0}}$ = 55 °C
- Test phase L3: 48 hours stand-by
- Test phase L4: discharge until steady-state is reached

Table 12 — Flow rates and store inlet temperatures for Test L (group 3)

Test phase	Process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,0}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{\mathrm{D,0}}$ °C
L1	conditioning	0	—	—	0,5 × $\dot{v}_{\mathrm{n}}$	20.00	variable
L2	charge	0.5 × $\dot{v}_{\mathrm{n}}$	60.00	variable	0	—	—
L3	stand-by	0	—	—	0	—	—
L4	discharge	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable

6.3.2.1.4.4 Group 4

Test L:

- Test phase L1: conditioning until steady-state is reached
- Test phase L2: charge with constant charge power of $\tilde{P}_{\mathrm{C}} = 1.0 \times \tilde{P}_{\mathrm{n}}$ until $\vartheta_{\mathrm{C,0}}$ = 60 °C
- Test phase L3: 48 hours stand-by
- Test phase L4: discharge until steady-state is reached

Table 13 — Flow rates and store inlet temperatures for Test L (group 4)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,0}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{\mathrm{D,0}}$ °C
L1	conditioning	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable
L2	charge	1.2 × $\dot{v}_{\mathrm{n}}$	variable	variable	0	—	—
L3	stand-by	0	—	—	0	—	—
L4	discharge	0	—	—	0.5 × $\dot{v}_{\mathrm{n}}$	20.00	variable

6.3.2.1.5 Determination of the heat transfer capacity rate and the position of the auxiliary heat exchanger(s) (TEST NiA)

NOTE 1 If there is more than one additional heat exchanger, *i* indicates the number of the heat exchanger.

NOTE 2 The exact position of the upper connection of an upper (auxiliary) heat exchanger is important, if it is near to the top and causes a thermal stratification inside the store. The determination of this position by means of the test method described below is only in that case possible.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The connections of the auxiliary heat exchanger the heat transfer capacity rate of which shall be determined shall be fitted to the charge circuit of the testing stand according to the manufacturer's instruction.

Test NiA:

- Test phase NiA1: conditioning until steady-state is reached
- Test phase NiA2: charge with constant charge power of $\tilde{P}_C = 1.0 \times \tilde{P}_n$ until temperature at the auxiliary heating sensor is equal 60 °C
- Test phase NiA3: discharge until steady-state is reached

Table 14 — Flow rates and store inlet temperatures for Test NiA (group 2 or 4)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
NiA1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
NiA2	charge	1.0 × $\dot{v}_n$	variable	variable	0	—	—
NiA3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.2.1.6 Determination of the position (s) and length(s) of the electrical heating sources(s) (TEST EiA)

The determination of the (vertical) position(s) of the electrical heating sources(s) is necessary if it/they are installed horizontally.

The length (as a model parameter) of the electrical heating source(s) shall be determined, if it/they is/are installed vertically in the top of the store.

This test applies only to stores with electrical heating sources(s).

NOTE If there is more than one electrical heating source, *i* indicates the number of the heating source.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The charging connections shall be closed and all charging heat exchangers shall be filled with water. The closed connections shall be insulated in the same way as the store.

Test EiA:

- Test phase NiA: conditioning until steady-state is reached
- Test Phase EiA2: charge with the nominal electrical power (specified by the manufacturer) until the heater is switched off by the thermostat (ϑ_{set} = 60 °C)
- Test phase EiA3: discharge until steady-state is reached

Table 15 — Flow rates and store inlet temperatures for Test EiA

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
EiA1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
EiA2	charge	0	—	—	0	—	—
EiA3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

6.3.2.1.7 Determination of the degradation of thermal stratification during stand-by

A parameter describing the degradation of thermal stratification during stand-by shall only be determined, if stratification occurs during usual operation (e. g. for a store of group 4 that is charged and discharged mixed, this parameter can not be determined).

To obtain this parameter, the upper (auxiliary) part of the store is charged and discharged twice in the same way. The first time the discharge is performed immediately after charging, the second time a stand-by of 24 hours is included. The determination of the parameter describing degradation of thermal stratification during stand-by is based on the 'comparison' of the two draw off profiles by means of parameter identification.

6.3.2.1.7.1 Group 1 and Group 3 (TEST NA and TEST NB)

The test of stores of group 3 is only necessary, if they enable a stratified discharge.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The connections which enable a complete charge of the auxiliary part of the store shall be fitted to the charge circuit of the testing stand.

Test NA:

- Test phase NA1: conditioning until steady-state is reached
- Test phase NA2: charge until the integrated flow rate $\dot{V}_C$ = 0.5 × V_n
- Test phase NA3: discharge until steady-state is reached

Table 16 — Flow rates and storage device inlet temperatures for Test NA (group 1 and 3)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
NA1	conditioning	0	—	—	0.5 × $\dot{v}_n$	20.00	variable
NA2	charge	0.5 × $\dot{v}_n$	60.00	variable	0	—	—
NA3	discharge	0	—	—	0.5 × $\dot{v}_n$	20.00	variable

Test NB:

- Test phase NB1: conditioning until steady-state is reached
- Test phase NB2: charge until the integrated flow rate $\dot{V}_C$ = 0.5 × V_n
- Test phase NB3: 24 hours stand-by
- Test phase NB4: discharge until steady-state is reached

Table 17 — Flow rates and store inlet temperatures for Test NB (group 1 and 3)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
NA1	conditioning	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
NA2	charge	0.5 × $\dot{V}_n$	60.00	variable	0	—	—
NA3	stand-by	0	—	—	0	—	—
NA4	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable

6.3.2.1.7.2 Group 2 and Group 4 with an auxiliary heat exchanger (TEST NB)

The test of stores of group 4 is only necessary, if they enable a stratified discharge. The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The heat exchanger which enable a charge of the auxiliary part of the store, shall be connected to the charge circuit of the testing stand.

NOTE Test NA has already been performed according to 6.3.2.1.5.

Test NB:

- Test NB 1: conditioning until steady-state is reached
- Test phase NB2: charge with constant charge power of P_c = 2.0 • P_n until the temperature at the position of the auxiliary heating sensor is 60 °C
- Test phase NB3: 24 hours stand-by
- Test phase NB4: discharge until steady-state is reached

Table 18 — Flow rates and store inlet temperatures for Test NB (group 2 and 4)

Test phase	process	charge circuit			discharge circuit		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
NB1	conditioning	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
NB2	charge	1.0 × $\dot{V}_n$	variable	variable	0	—	—
NB3	stand-by	0	—	—	0	—	—
NB4	discharge	0	—	—	0.5 × $\dot{V}_n$	20,00	variable

6.3.2.1.7.3 Stores with electrical heat sources

This test shall only be performed if an electrical auxiliary heater is used.

The storage device shall be connected to the testing stand according to 6.2.

The connections which enable a complete discharge of the store shall be fitted to the discharge circuit of the testing stand.

The charging connections shall be closed and all charging heat exchangers shall be filled with water. The closed connections shall be insulated in the same way as the store.

Test EB:

- Test phase EB1: conditioning until steady-state is reached
- Test phase EB2: charge with the nominal electrical power (according to the manufacturer's instructions)
- Test phase EB3 24 hours stand-by
- Test phase EB4: discharge until steady state is reached

Table 19 — Flow rates and store inlet temperatures for Test EB

Test phase	process	Charge circuit			discharge circuit		
		$\tilde{\dot{V}}_{\mathrm{C}}$ l/h	$\tilde{\vartheta}_{\mathrm{C,i}}$ °C	$\tilde{\vartheta}_{\mathrm{C,0}}$ °C	$\tilde{\dot{V}}_{\mathrm{D}}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{\mathrm{D,0}}$ °C
EB1	conditioning	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
EB2	charge	0	—	—	0	—	—
EB3	stand-by	0	—	—	0	—	—
EB4	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable

6.3.2.1.8 Test procedure for combistores

Charging and discharging the entire store implies connections of the charge/discharge circuits to the uppermost and lowermost direct ports available at the tank. Full discharging is required for conditioning of the store and for the final discharge phase. Full charging is required for all discharge tests which require that the entire store is charged.

The series of the performed tests should comprise two tests which include stand-by periods. One test is for the entire store, to determine the heat loss capacity rate. The other test concerns only the part of the store which is heated up (usually the auxiliary heated part).This test is used to determine the degradation of thermal stratification during stand-by. The stand-by period should be such that the losses during this period are approximately half of the stored energy. For these two tests with stand-by periods, the same test should also be performed without a stand-by period.

Flow rates and power values are given as examples only. The chosen flow rate or power should be suited to the type of component which will be used with those connections.

6.3.2.1.8.1 General charge direct (TEST CD)

- Test phase CD1: conditioning until steady-state is reached

- Test phase CD2: charging through test ports until $\vartheta_{C,0}$ = 55 °C
- Test phase CD3: optional stand-by until approximately half stored energy is lost to ambient
- Test phase CD4: direct discharge of the entire store until steady-state is reached

Table 20 — Flow rates and store inlet temperatures for Test CD

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
CD1	conditioning	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
CD2	charge	0.5 × $\dot{V}_n$	60.00	variable	0	—	—
CD3	stand-by	0	—	—	0	—	—
CD4	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable

NOTE If the ports are used with a boiler the operating temperature of which is greater than 60 °C (e. g. a wood boiler), a higher inlet temperature ($\vartheta_{C,i}$) may be used.

6.3.2.1.8.2 General charge indirect (TEST CI)

- Test phase C11: conditioning until steady-state is reached
- Test phase CI2: charge through test heat exchanger at constant power of $\tilde{P}_C = 2.0 \times \tilde{P}_n$ until $\vartheta_{C,0}$ = 60 °C
- Test phase CI3: optional stand-by until approximately half stored energy is lost to ambient
- Test phase CI4: direct discharge of the entire store until steady-state is reached

Table 21 — Flow rates and store inlet temperatures for Test CI

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_C$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_D$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
CI1	conditioning	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
CI2	charge	1.2 × $\dot{V}_n$	variable	variable	0	—	—
CI3	stand-by	0	—	—	0	—	—
CI4	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable

If the heat exchanger is used at different flow rates, the test should be performed four times, using, if possible, the following different charging conditions: constant power P_n at high and low flow rates, as well as constant power $0.5P_n$ at low and high flow rates.

6.3.2.1.8.3 General discharge direct (TEST DD)

- Test phase DD1: conditioning until steady-state is reached

- — Test phase DD2: charging of the entire store until $\vartheta_{C,0}$ = 55 °C
- — Test phase DO3: discharge through test ports until $\vartheta_{D,O}$ = 30 °C
- — Test phase DD4: direct discharge of the entire store until-steady state is reached

Table 22 — Flow rates and store inlet temperatures for Test DD

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
DD1	conditioning	0	—	—	0.5 x $\dot{V}_n$	20.00	variable
DD2	charge	0.5 × $\dot{V}_n$	60.00	variable	0	—	—
DD3	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable
DD4	discharge	0	—	—	0.5 × $\dot{V}_n$	20.00	variable

6.3.2.1.8.4 General discharge indirect (TEST DI)

- — Test phase DI1: conditioning until steady-state is reached
- — Test phase DI2: charge of the entire store until $\vartheta_{c,o}$ = 55 °C
- — Test phase DI3: discharge through the test heat exchanger until $\vartheta_{D,O}$ = 30 °C
- — Test phase DI4: direct discharge of the entire store until steady state is reached

Table 23 — Flow rates and store inlet temperatures for Test DI

Test phase	process	charge			discharge		
		$\tilde{\dot{V}}_{C}$ l/h	$\tilde{\vartheta}_{C,i}$ °C	$\tilde{\vartheta}_{C,0}$ °C	$\tilde{\dot{V}}_{D}$ l/h	$\tilde{\vartheta}_{D,i}$ °C	$\tilde{\vartheta}_{D,0}$ °C
DI1	conditioning	0	—	—	0.5 x $\dot{V}_n$	20.00	variable
DI2	charge	0.5 x $\dot{V}_n$	60.00	variable	0	—	—
DI3	discharge	0	—	—	0.5 x $\dot{V}_n$	20.00	variable
DI4	discharge	0	—	—	0.5 x $\dot{V}_n$	20.00	variable

If the heat exchanger is intended for domestic hot water preparation, this test shall be performed three times under different discharge conditions. To each of these three discharge conditions the following two charge conditions shall apply: Store fully charged and auxiliary part charged. In all, six tests shall be performed. The following discharge conditions should apply:

- — Low flow rate
- — High flow rate

The test shall be repeatedly performed under following conditions: Intermittent discharge at high flow rate with 10 minutes discharge and 10 minutes stand-by. This test does not need to be performed if it can be assumed that the heat transfer capacity rate of the discharge heat exchanger will not be time dependent.

6.3.2.2 Evaluation of the test sequences described according to 6.3.2.1 by means of parameter identification (fit)

When all necessary tests as described in 6.3.2.1 are performed, identification of store parameters shall be carried out, using a numerical store model that fulfils the requirements given in annex B and an adequate parameter identification algorithm that fulfils the requirements given in annex C.

The store model shall meet the requirements of the benchmark tests given in annex B.

For the parameter identification the measuring data can be compressed and/or converted to constant time steps. In both cases, the data records shall represent mean values for the corresponding time step. During charge and discharge, the time steps should not exceed 3 minutes. During stand-by, a maximum time step of 15 minutes is allowed.

For the fit the measured values of the inlet store temperatures, ambient temperature, flow rates and the power of the electrical heating source(s) shall be used as inputs. Since at the beginning of each test the store is always conditioned to 20 °C, no skip time is required. Hence the data used for fitting, shall start with the second test phase, and ϑ_s = 20 °C shall be used as initial temperature for the store model.

All parameters which are determined by parameter identification shall be identified during one parameter identification process.

For every time step during the fit for each connection ‘X’(X = C for charge and X=D for discharge), the absolute difference between the transferred measured and predicted power shall be calculated by

$$\Delta P_x = \left| P_{x,p} - P_{x,m} \right|$$

where:

$$P_{x,p} = \bar{\rho} \times \bar{c}_p \times \dot{V} \times (\vartheta_{x,i} - \vartheta_{x,0,p})$$

$$P_{x,m} = \bar{\rho} \times \bar{c}_\rho \times \dot{V} \times (\vartheta_{x,i} - \vartheta_{x,o,m})$$

The function f(t) which shall be minimized is the integral of the sum over all absolute power differences calculated by

$$f(t) = \int_t \sum_x \Delta P_x \, dt$$

7 Store test combined with a system test according to ISO 9459-5

The procedure is in principle similar to 6.3.2.1 except that the data are gained during a whole system test according to ISO 9459-5 with additional sensors in the collector loop. The use of additional sensors in the collector loop is, however, only allowed if the normal function of the system is not affected.

- Using measuring equipment according to ISO 9459-5, the following data shall be measured and recorded additionally to the measurements required by ISO 9459-5:

- The volumetric flow through the collector loop as well as the inlet temperature at the store or heat exchanger and the outlet temperature at the store or heat exchanger of the collector loop.

- If the system is equipped with an integrated hot water auxiliary heating, the volumetric flow through the auxiliary loop as well as the inlet temperature at the store or heat exchanger and the outlet temperature at the store or heat exchanger of the auxiliary loop.
- If an immersed electrical auxiliary heater is fitted to the store, no additional measurements are necessary as P_{aux} is already measured.

For the determination of the store parameters by means of parameter identification see 6.3.2.2.

8 Test report

8.1 General

The test report shall include:

- a detailed description and the technical data of the tested store (based on the manufacturer's instruction)
- the determined parameters and a description of them
- reference to the used store model (parameters for simulation)

8.2 Description of the store

The description of the store shall be based on the information provided by the manufacturer.

a) **General data:**
  - Manufacturer:
  - Type:
  - Year of construction:
  - Serial number:
  - Nominal volume:
  - Description and drawing of the schematic design:

b) **Stored water:**
  - Volume:
  - Material and corrosion protection (only in case of drinking +water):
  - Maximum operation pressure:
  - Maximum operation temperature:
  - Thermal insulation:
  - Diameter and type of connections:

c) **Electrical heating source(s):**
  - Voltage:
  - Nominal heating power:
  - Diameter and type of connection:

d) **Heat exchanger(s):**
  - Volume:
  - Material and corrosion protection (only in case of drinking water):
  - Type of pipes (with/without ribs, coil etc.):
  - Size of the area for heat transfer:
  - Position inside the store:
  - Maximum operation pressure:
  - Maximum operation temperature:
  - Diameter and type of connections:

8.3 Test results

NOTE 1 Some of the parameters used for the characterization of the thermal behaviour of the store are related to the used store model. Therefore, information on these parameters and the store model should be provided.

a) **Geometrical data:**
- Weight of the complete storage device (empty):
- Maximum height of the complete storage device:
- Maximum diameter of the complete storage device:

b) **Volumes:**
- Volume of the stored water:
- Volume of the heat exchanger(s):

c) **Thermal parameters:**
- Thermal capacity of the entire store:
- Thermal capacity of appropriate parts of the store (e. g. auxiliary heated part):
- Stand-by heat loss capacity rate (optional: operating heat loss capacity rate):
- Parameter describing the degradation of thermal stratification during stand-by:
- Parameter describing the quality of thermal stratification during direct discharge:
- Heat transfer capacity rate $(UA)_{hx,s}$ of the heat exchanger(s). The test conditions (fluid, temperatures, flow rate, transferred heating power) for the determination of the heat transfer capacity rate shall be mentioned in the test report.

NOTE 2 If a diagram of $(UA)_{hx,s}$ s over the temperature is included in the test report, the transferred heating power at each point of the diagram should be indicated, if the transferred heating power varies for the different points of the plotted $(UA)_{hx,\,s}$ values.

In addition, the draw-off profiles for two different draw-off flow rates (e. g. from Test C and Test S) and the two draw-off profiles used for the determination of the parameter describing the degradation of thermal stratification during stand-by (e. g. from Test NiA and Test NiB or from Test EiA and Test EiB), should be included.

8.4 Parameters for the simulation

All parameters which are necessary to describe the thermal behaviour of the store in combination with a suitable numerical calculation model shall be recorded. In addition to the parameters listed in 8.3, the following parameters are required:

a) Data of the fluid (e. g. constant values for the density and the specific heat capacity)

b) Position of the

- inlet and outlet connection(s) for direct charge and discharge
- inlet and outlet connection(s) of the heat exchangers

c) Information on the ability for stratified charging/discharging

Annex A
(normative)

Requirements for the numerical store model

A.1 General

For the system performance characterization by means of component testing and whole system simulation, numerical models which are able to describe the thermal behaviour of the components are required.

This annex gives instructions for modeling the store, in order to enable a uniform modeling of the hot water store.

A.2 Assumptions

In order to simplify the model, it is possible to use the following assumptions to describe the thermal behaviour of the store.

- Each component of the store (e.g. tank, heat exchanger) can be assumed to be isothermal in horizontal direction.
- Temperature inversion inside the tank, which means $d\vartheta / dz < 0$, can be removed by an appropriate algorithm at the end of a time step.
- The thermal capacity of the storage vessel can be neglected. This capacity can be added to the thermal capacity of the stored water.
- The thermal capacity of the pipes of the heat exchanger(s) can be neglected.
- The physical effects of heat conduction in the water and the metal wall of the tank and the convection in the water can be lumped together in an effective vertical thermal conductivity.

A.3 Energy balance

For models which are based on a finite difference method with segments (nodes) of equal capacities, the energy balance for a node (i) of the stored water is represented by equation (A.1). The index (i+1) indicates the node above (i) and the index (i-1) indicates the node below (i).

The left member of equation (A.1) describes the temporary change of the internal energy. The heat transport caused by the mass flows through the number of ‘P’ double ports is represented by the first sum on the right member. The electrical auxiliary heater is treated as an internal heat source. The heat transfer between the nodes of the heat exchanger and the stored water is described by the third term. If there are more heat exchangers, additional terms shall be added. The fourth term represents effects which can be described by using an effective vertical thermal conductivity. The last term considers the heat loss to the ambient.

$$\begin{aligned}\frac{C_{\mathrm{s}}}{N} \times \frac{d\vartheta_{\mathrm{s,i}}}{\mathrm{dt}} = {} & \sum_{\mathrm{p}} \dot{m}\mathrm{dp} \times \mathrm{c}_{\mathrm{p,s}} \times \left[\xi_1\left(\vartheta_{\mathrm{s,i\text{-}1}} - \vartheta_{\mathrm{s,i}}\right) + \xi_1 \times \left(\vartheta_{\mathrm{s.i}} - \vartheta_{\mathrm{s,i+1}}\right)\right] + \frac{Q_{\mathrm{aux}}}{n_{\mathrm{aux}}} + \xi_{\mathrm{hx,3}} \times \frac{(UA)_{\mathrm{hx,s}}}{\mathrm{n}_{\mathrm{hx}}} \times \left(\vartheta_{\mathrm{hx,i}} - \vartheta_{\mathrm{s,i}}\right) \\ & + \lambda_{\mathrm{eff}} \times \frac{A}{Z} \times N \times \left[\left(\vartheta_{\mathrm{s,i+1}} - \vartheta_{\mathrm{s,i}}\right) + \left(\vartheta_{\mathrm{s,i\text{-}1}} - \vartheta_{\mathrm{s,i}}\right)\right] - \frac{(UA)_{\mathrm{s,a,k}}}{\mathrm{n}_{\Delta\mathrm{z,k}}} \times \left(\vartheta_{\mathrm{s,i}} - \vartheta_{\mathrm{am}}\right)\end{aligned} \qquad \text{(A.1)}$$

where

A is the cross-section are of the stored volume

C_s is the thermal capacity of the tank

C_p is the specific heat capacity

$\dot{m}_{dp}$ is the mass flow rate through double port p

N is the number of vertical nodes

n_{aux} is the number of nodes occupied by the electrical auxiliary heating element

$n_{\Delta z,k}$ is the number of nodes occupied by zone k with the length Δz

n_{hx} is the number of nodes occupied by the heat exchanger hx

p is the number of double ports

$(UA)_{hx,s}$ is the heat transfer capacity rate for the heat exchanger to the store

$(UA)_{s,a,k}$ is the heat loss capacity rate for the zone k

Z is the height of the store

$\dot{Q}_{aux}$ is the heat flow from the auxiliary heating element

ϑ is the temperature

λ_{eff} is the effective vertical thermal conductivity

The logical switches ξ_1 are used in the following way:

$-\xi_1 = 1$ if $\dot{m}_{dp}$ from bottom to top (upwards), otherwise $\xi_1 = 0$

$-\xi_1 = 1$ if $\dot{m}_{dp}$ from top to bottom (downwards), otherwise $\xi_2 = 0$

$-\xi_{hx,3} = 1$ if node i of the tank is in contact with node i of heat exchanger hx, otherwise $\xi_{hx,3} = 0$

Annex B

(normative)

Store model benchmark tests

B.1 General

The benchmark test in this annex shall ensure that the store model fulfils fundamental requirements. Hence, for simplified operating cases the results calculated by the model shall be compared with the analytical solutions of the differential equations.

B.2 Temperature of the store during stand-by

It is assumed that the store is fully mixed and supplied with a homogeneous insulation.

The decrease of the temperature of the store during stand-by can be calculated by equation (B.1).

$$\vartheta(t) = \vartheta_{\mathrm{am}} + \left(\vartheta_0 - \vartheta_{\mathrm{am}}\right) \cdot e \frac{-(UA)_{\mathrm{s,a}}}{C_{\mathrm{s}}} \cdot t \qquad \text{(B.1)}$$

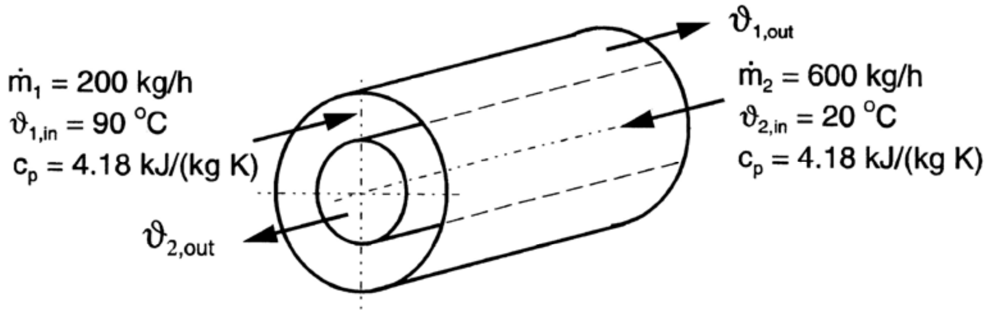
The temperature as a function of time ($0 \leq t \leq 400$ h) shall be calculated by equation (B.1) (*analytical)* and *by* the store model *(numerical)* with the following parameters:

—	constant ambient temperature:	$\vartheta_{\mathrm{am}} = 20$ °C
—	initial temperature:	$\vartheta_0 = 60$ °C
—	thermal capacity of the store (constant):	$C_{\mathrm{s}} = 2.0$ MJ/K
—	heat loss capacity rate:	$(UA)_{\mathrm{s,a}} = 7.0$ W/K

This benchmark test shall be considered as valid if the maximum difference between the temperatures calculated in an analytical and numerical way is less then 0.001K

If the model is part of a simulation program which enables the use of different time steps, this benchmark test shall be carried out for time steps of min and 60 min.

B.3 Heat transfer from heat exchanger to store


$\dot{m}_1 = 200$ kg/h
$\vartheta_{1,\mathrm{in}} = 90$ °C
$c_p = 4.18$ kJ/(kg K)
$\vartheta_{2,\mathrm{out}}$
$\vartheta_{1,\mathrm{out}}$
$\dot{m}_2 = 600$ kg/h
$\vartheta_{2,\mathrm{in}} = 20$ °C
$c_p = 4.18$ kJ/(kg K)

Key
1 Heat transfer rate $(UA)_{\mathrm{h1,s}} = 1667$ W/K

Figure B.1—Store considered as a twin tube heat exchanger

For the parameters given in Figure 4 the results of the analytical solution are listed in Table B.1.

Table B.1 — Results of the analytical solution

$\vartheta_{1,\mathrm{out}}$ °C	$\vartheta_{2,\mathrm{out}}$ °C	$\dot{Q}$ kW
20.391	**43.202**	**16.165**

This benchmark test may be considered as valid if the maximum difference between the calculation in an analytical and numerical way is less than 0.2 K for the temperatures less than 1 % (based on the analytical solution) for the transferred power.

Annex C
(normative)

Benchmarks for the parameter identification

This benchmark test shall ensure that the evaluation procedure based on parameter identification leads to acceptable results.

A set of test and verification sequences for a solar domestic hot water store is available from:

DIN Deutsches Institut für Normung e. V.
Normenausschuß Heiz- und Raumlufttechnik (NHRS)
Burggrafenstraße 6
D-10787 Berlin

Based on this data, the parameters of the store shall be determined by means of parameter identification. Using the determined parameters, the verification test sequences shall be re-simulated.

This benchmark test may be considered as valid if the following criteria for the acceptance of the test results are fulfilled:

For each sequence the measured and predicted (simulated) energies transferred through each charge and discharge connection shall be calculated separately. Periods used for conditioning at the beginning of the test sequence shall be excluded.

For each connection 'x' (x=C for charge and x=D for discharge) the relative error in transferred energy $\varepsilon_{x,}$ Q shall be calculated by

$$\varepsilon_{\mathrm{x,Q}} = \frac{Q_{\mathrm{x,p}} - Q_{\mathrm{x,m}}}{Q_{\mathrm{x,m}}} \times 100\,\% \tag{C.1}$$

If the relative error in transferred energy $\varepsilon_{\mathrm{x,Q}}$ exceeds 3.0 %, than the test is considered as not valid.

For each sequence the measured and predicted (simulated) heat power transferred through each charge and discharge connection shall be calculated separately. Periods used for conditioning at the beginning of the test sequence shall be excluded.

Every time step during the simulation for each connection V (x=C for charge and x=D for discharge) the absolute difference between the transferred and predicted heat power shall be calculated byThe mean deviation in transferred heat power shall be calculated by

$$\Delta P_{\mathrm{x}} = \left| P_{\mathrm{x,p}} - P_{\mathrm{x,m}} \right| \tag{C.2}$$

The mean transferred heat power shall be calculated by

$$\Delta\overline{P} = \frac{\int\limits_{\mathrm{t}} \sum\limits_{\mathrm{x}} \Delta P_{\mathrm{x}}\, dt}{\sum\limits_{\mathrm{x}} t_{\mathrm{x,t}}} \tag{C.3}$$

The mean transferred heat power shall be calculated by

$$\overline{P} = \frac{\int_{\mathrm{t}} \sum_{\mathrm{x}} P_{\mathrm{x}}\, dt}{\sum_{\mathrm{x}} t_{\mathrm{x,t}}} \tag{C.4}$$

The relative error in mean transferred heat power ε_{p} shall be calculated by

$$\varepsilon_{\mathrm{p}} \frac{\Delta\overline{\mathrm{P}}}{\overline{\mathrm{P}}} \times 100\,\% \tag{C.5}$$

If the relative error in mean transferred heat power ε_p exceeds 3.0 %, then the test is considered as not valid.

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